

## Detector performance of the NEWAGE experiment

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NEWAGE(NEw generation WIMP search with an Advanced Gaseous tracking device Experiment) project is a direction-sensitive dark matter search experiment with a gaseous micro time-projection-chamber( $\mu$ -TPC). We report on the performance of the  $\mu$ -TPC with a detection volume of  $23 \times 28 \times 30 \text{ cm}^3$  operated with a carbon-tetrafluoride ( $\text{CF}_4$ ) of 0.2 bar.

*Keywords:* Time projection chamber; Micro-pattern detector; dark matter

### 1. Introduction

Weakly interacting massive particle(WIMPs) are thought to be one of the most plausible candidates of the dark matter. Most of the dark matter search experiments are designed to measure only the energy deposition on the nucleus by a WIMP-nucleus scatterings. Because the amplitude of an annual modulation signal is only a few % in the rate, positive signatures of the WIMPs are very difficult for detection with only the energy information. Owing to the motion of the solar system with respect to the galactic halo, the direction-distribution of the WIMP velocity observed at the earth is expected to show an asymmetry like a wind of WIMPs. Attempts to detect a positive signature of WIMPs by measuring the recoil angles have been carried out<sup>1-5</sup> ever since it was indicated to be an alternative and a reliable method.<sup>6</sup> Gaseous detectors are one of the most appropriate devices for detecting this WIMP-wind. DRIFT project has performed under-

ground runs for more than two years with a  $1\text{m}^3$  time projection chamber (TPC) filled with a low pressure  $\text{CS}_2$  gas.<sup>4</sup> We proposed to use a carbon-tetrafluoride ( $\text{CF}_4$ ) as a chamber gas of our time projection chambers with a micro-pixel chamber readout ( $\mu$ -TPC) aiming to detect WIMPs via spin-dependent (SD) interactions.<sup>7</sup> In this paper, the performance of the  $\mu$ -TPC is described.

## 2. Measurements

### 2.1. *Micro-TPC*

A  $\mu$ -TPC is a time projection chamber with a micro pixel chamber ( $\mu$ -PIC<sup>8</sup>) readout, developed for the detection of tracks of charged particles with fine spatial resolutions.<sup>9</sup> A  $\mu$ -PIC is a gaseous two-dimensional position-sensitive detector manufactured by the printed circuit board (PCB) technology. With the PCB technology, large-area detectors can, in principle, be mass-produced, which is an inevitable feature for a dark matter detector. The pixel-pitch of the  $\mu$ -PIC is  $400\text{ }\mu\text{m}$  and the detection area is  $31\times 31\text{ cm}^2$ . We had studied the performance of a small size ( $10\times 10\times 10\text{ cm}^3$ )  $\mu$ -TPC with a 0.2 bar  $\text{CF}_4$  gas.<sup>9</sup> We then developed a large-volume  $\mu$ -TPC with a detection volume of  $23\times 28\times 30\text{ cm}^3$ , and studied its fundamental properties with an  $\text{Ar-C}_2\text{H}_6$  gas mixture at a normal pressure.<sup>10</sup> The data acquisition system is described in Ref.<sup>11</sup> We will describe the performance of the  $\mu$ -TPC with a 0.2 bar  $\text{CF}_4$  gas in the following subsections.

### 2.2. *Energy calibration*

We calibrated the energy of the  $\mu$ -TPC with  $\alpha$  particles generated by the  $^{10}\text{B}(\text{n}, \alpha)^7\text{Li}$  ( $Q=2.7\text{MeV}$ ) reaction. We set a glass plate with a size of  $27\times 70\times 1\text{mm}^3$  coated with a thin  $0.6\text{ }\mu\text{m}$   $^{10}\text{B}$  layer in the  $\mu$ -TPC. The picture of the boron-coated glass set in the  $\mu$ -TPC is shown in the left panel of Fig. 1. Fast neutrons from  $^{252}\text{Cf}$  were moderated and the thermalized neutrons were captured by the  $^{10}\text{B}$  layer. Alpha particles are emitted from the layer and the integrated two-dimensional image is shown in the right panel of Fig. 1. It is seen that the  $\alpha$  particles from the  $^{10}\text{B}$  layer are detected and the corresponding position has a high counting rate.

The measured and simulated spectra are shown in Fig 2. The edge which corresponds to the full energy deposition of the  $\alpha$  particle and the  $\alpha+\text{Li}$  are seen in the both spectra. The elastic scatterings of the fast neutrons from the  $^{252}\text{Cf}$  source gives an increase of the lower energy part of the measured energy spectrum.

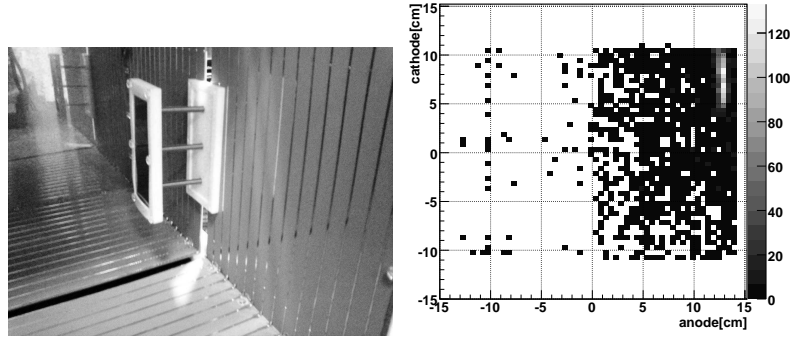


Fig. 1. Picture of the glass plate coated with a boron layer(right) and an integrated event display of a calibration measurement.

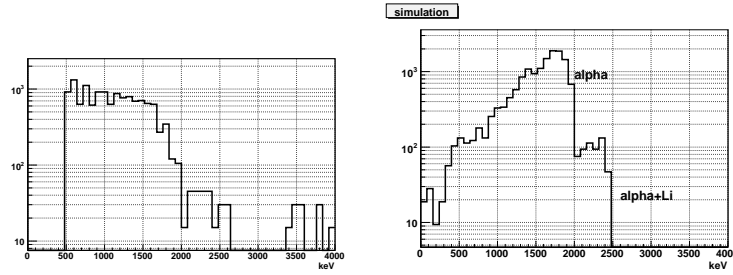


Fig. 2. Measured(left) and simulated spectra of the calibration

Alpha peaks(5.6 MeV, 6.1 MeV, 7.2 MeV) from the decays of the radon daughters are also used for the energy calibration. The energy resolution was also measured with these alpha peaks and the energy resolution was 50%(FWHM) in the high energy(3-8 MeV) region.

### 2.3. Absolute detection efficiency of nuclear recoils

The detection and the event-selection efficiency was measured by irradiating the fast neutrons from  $^{252}\text{Cf}$ . Here the events which satisfied the following three conditions were selected as a nuclear recoil events.

- The track is in the fiducial volume ( $21.5 \times 22 \times 31 \text{ cm}^3$ ).
- The track has more than three digital hits.
- The track is shorter than 1cm.

The first requirement is the fiducial cut to reject the protons from the drift wall, the second is for the direction determination, and the third one is for the gamma-ray rejection. The detection and the selection efficiency was about 40% at 100 keV and the efficiency in the energy region of 100-400keV (DM energy region)  $\epsilon$  was fitted by  $\epsilon = 1.0 \cdot \text{erf}((E - 45.8)/165.2)$ , where  $\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-x^2) dx$  is the error function and  $E$  is the detected energy. The measured efficiency and the best fit function are shown in the left panel of Fig. 3

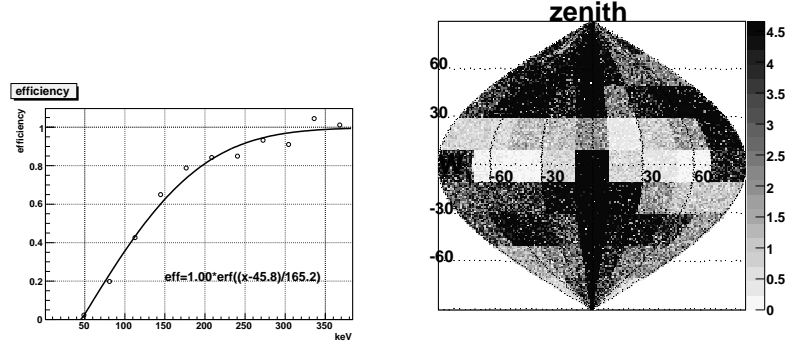


Fig. 3. Absolute detection efficiency of the nuclear recoils (left) and the relative direction-dependent response.

#### 2.4. Direction-dependent detector response

The direction-dependent detector response is one of the most important properties for the direction-sensitive dark matter search. We irradiated the fast neutrons from various position to generate "a uniform recoils". We determined the direction of the selected events by fittings the digital hits and the direction-map is shown in the right panel of Fig. 3. Because we don't detect the head-and-tail of the tracks, this map is restricted to the half sky, *i. e.*  $-90^\circ < \text{azimuth} < 90^\circ$  and  $-90^\circ < \text{zenith} < 90^\circ$ . The response is not very flat nor symmetric because of the inhomogeneity of the detector. A much more flat response is expected for the next detector with improved manufacture technologies.

### 2.5. Gamma-ray rejection

It is one of the outstanding advantage of the gaseous TPC that the track-length and the energy-deposition correlation provides a strong gamma-ray rejection.<sup>9</sup> We measured the gamma-ray rejection factor by irradiating the gamma-rays from a  $^{137}\text{Cs}$  source. Measured spectra with and without the gamma-ray source and the background-subtracted spectrum are show in Fig. 4 We define the gamma-ray miss-identification factor (or the electron-detection efficiency)  $f_e$  as

$$f_e \equiv \frac{R_\gamma - R_{\text{BG}}}{R_{\text{sim}}}, \quad (1)$$

where  $R_\gamma$  and  $R_{\text{BG}}$  are the the measured counting rate DM energy region with and without the gamma-ray source and  $R_{\text{sim}}$ , is the expected rate of the electrons which has a initial energy in the DM energy region. The result was  $f_e < 2.0 \times 10^{-4}$ . This "rejection factor" was restricted by the background neutrons in the surface laboratory.

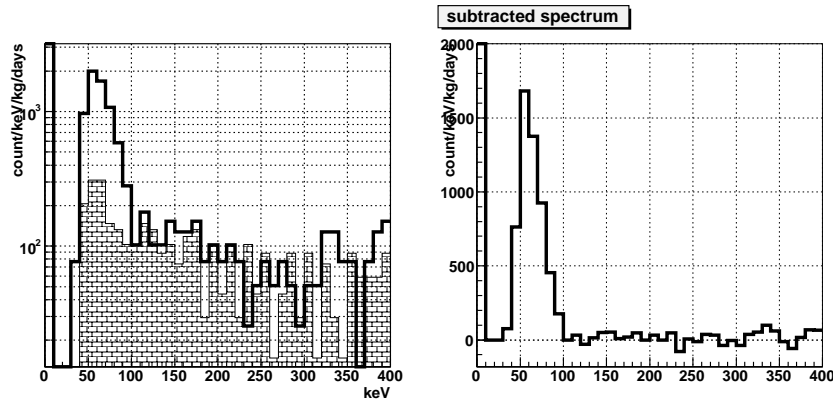


Fig. 4. The energy spectra measured with(solid) and without(hatched) the gamma-ray source(left). The background-subtracted(=solid-hatched) spectrum(right).

### 3. Summary

We measured the performance of the  $\mu$ -TPC and obtained the following results.

- The detector is calibrated with  $\alpha$ -particles.

- The absolute efficiency is about 0.4% at 100keV.
- The electron miss-identification probability is less than  $2 \times 10^{-4}$  in the 100-400 keV energy range.
- The direction dependent response is measured. After a pilot run in the surface laboratory, we will start an underground measurement in Kamioka Observatory in January, 2007.

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